

Hydrodynamic behaviour of a stilling pond

Comportement hydrodynamique d'un bassin de décantation

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RESUME

Le présent exposé propose une explication des comportements hydrodynamiques d'une structure particulière de bassin de décantation au moyen de la théorie du jet turbulent. Une série d'expériences employant des nombres de Froude différents et des largeurs de bassins de décantation différentes a été effectuée afin d'observer et de quantifier la croissance du jet de paroi et la perte de vitesse en fonction de la distance par rapport à l'entrée des effluents. De plus, les résultats expérimentaux montrent que les profils de vitesse axiale pour différentes sections du jet étaient pratiquement semblables avec, toutefois, quelques différences par rapport au profil du jet plan classique. Dans le cadre des paramètres testés, la largeur du bassin de décantation s'avère n'avoir aucun effet sur les caractéristiques du jet.

ABSTRACT

The proposed paper contributes to an understanding of hydrodynamic behaviours of a particular stilling pond structure by means of turbulent wall jet theory. A set of experiments with different Froude numbers and different stilling pond widths was used to observe and quantify the growth of the wall jet and the decay of the velocity scale with the distance from the inlet. Moreover the experimental results showed that the axial velocity profiles at different sections in the wall jet were almost similar, with some difference from the profile of the classical plane wall jet. In the range of experimental test parameters, the stilling pond width was found to be irrelevant on jet characteristics.

KEYWORDS

CSO Structure Design, Efficiency, Turbulent jet, Stilling pond.

INTRODUCTION

Combined sewer overflow (CSO) structures are used for diverting overflow discharge in water bodies during rainfall. Contemporary they provide for a small variation respect to the design value of discharge flowing to the treatment facilities.

In the last few years it has realized that the common CSO structures are unable to control both water discharge and pollution simultaneously. Moreover many sewer systems experience a 'first flush' effect where significant volumes of pollutants arrive at an overflow (and are spilled) in the early part of the storm. The worsening of urban surrounding has led to consider either new CSO structures or to use the common ones along with a flow equalization basin or a rainwater storage tank. Such devices, eventually together with real time control (RTC) systems, allow to reduce the pollution loads into the receiving water bodies by favouring the sedimentation processes.

The performance of basin or tank devices is different depending on their design volume. In fact significant volumes have an effect on both storm reduction peak (quantity) and sedimentation processes (quality). Conversely smaller volumes have mainly a quality effect.

The stilling pond overflow structure represents a typical example of the latter solution. In fact by expanding the incoming flow into a rectangular chamber settleable solids fall to the invert, while floatables rise to the surface where they are directed by a transverse scumboard to a tranquil region on the surface near the inlet. Here they are stored until the end of the storm when the water level reduction allows to collect also the floatable solids toward the throttling pipe.

An experimental investigation of stilling pond overflow structure has been conducted in the laboratory of the Department of Hydraulic and Environmental Engineering of University of Study of Naples Federico II. Although the laboratory model refers to design suggestions of several researchers (*Sharpe e Kirkbride*, 1959; *Balmforth*, 1982; *Balmforth ed al.*, 1994), it shows some innovative aspects.

The experimental tests presented in this paper were performed to study the hydrodynamic behaviours of the stilling pond structure by investigating the developing wall jet due to the flow inlet expansion in a limited extent chamber. The results will be addressed to the optimal design of the stilling pond.

The first set of experiments in clear water, with different Froude numbers and different stilling pond widths, was used to observe and quantify the growth of the wall jet and the decay of the velocity scale with the distance from the inlet. The results were studied and compared with that of a classical turbulent wall jet. The time-averaged axial velocity profiles at different sections in the wall jet were found to be quite similar, with some differences from the plane wall jet profile.

1 EXPERIMENTS

Experiments were performed in a 2.00 m long and a 0.36-0.70m wide Plexiglas stilling pond with a transversal embanked section and an approach pipe with an internal diameter $D=150$ mm. The dry weather flow channel of the stilling pond structure is semicircular ($D = 150\text{mm}$) with a lateral embankment slopes of 5%.

For overflowing the exceeding discharge a frontal weir device has been used. The overflow weir is maximum 60 cm wide and 47 cm high from the throttling pipe bottom. A scumboard was located at different longitudinal distances L_s from the inlet, respectively at 9 and 11D, with a depth of $1D$ from the bed (Figure 1).

The discharges were measured by flowmeters located in the supply lines and velocity distributions were measured along vertical sections at different longitudinal distances from the inlet (section S1 to S5 in Fig. 1), in the centerplane of the flume and at 8 cross-sections. An acoustic profiler, Signal Processing DOP2000, was used to acquire the vertical distribution of local velocities.

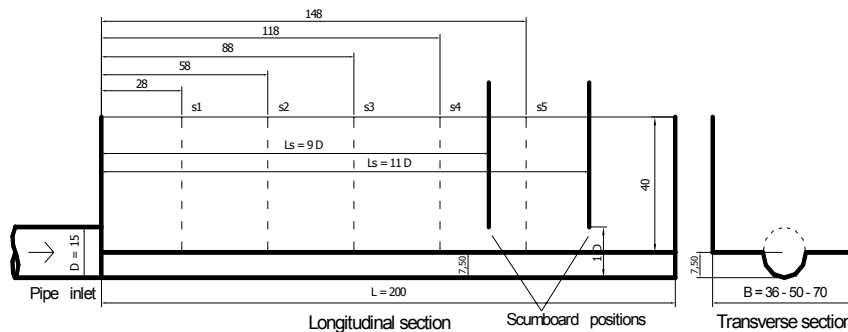


Fig. 1. Sketch of the investigated stilling pond structure (lengths in cm).

A set of experiments in clear water, with different approach Froude numbers, $Fo = U_{om}/(gD)^{0.5}$, and different stilling pond width, B , were conducted. Table 1 shows the primary details of the experiments. In Table 1, U_{om} is the mean velocity at the pipe inlet and Re the Reynolds number of the jet.

Experiment	B [cm]	Re	Fo	U_{om} [m/s]
E1	36	49,000-85,000	0.21-0.37	0.33-0.56
E2	50	49,000-85,000	0.21-0.37	0.33-0.56
E3	70	49,000-130,000	0.21-0.57	0.33-0.87

Table 1. Primary Details of Experiments

2 RESULTS

In order to define the hydrodynamic behaviour of the jet, one must first predict the characteristics of this flow phenomenon in terms of wall jet growth and velocity scale decay with the distance from the inlet. Fig. 2 shows the velocity profiles in the forward as well as in the reverse flows at several sections x for experiment E3 with $D/B=0.2$ and $Ls/L=0.85$; y is the distance above the bed, D is the diameter of the circular jet and U is the local mean velocity. The maximum reverse velocity at any station was found to occur near the water surface, except for section 1 ($s1$ in Fig.1 – $x = 11$ cm) (Ead and Rajaratnam, 2002, 2004).

Velocity measurements in the forward flow show clearly the structure of the wall jet. To test for the similarity of velocity profiles, the maximum velocity U_m at any station was chosen as the velocity scale, and the length scale b is equal to y where $U=0.5U_m$. Figure 3 shows a consolidated plot of the data for the E2 experiments with $D/B= 0.3$ and $Ls/L=0.85$ and 1. The velocity profiles in the forward flow are quite similar but somewhat different from the classical plane wall jet profile (Schwarz and Cosart 1961; Rajaratnam 1976). In fact in the present data, the distance y corresponding to $U_m/U=1$ is in the range 0.32 ± 0.40 times b , whereas for the classical plane wall jet the value is $0.16b$. Moreover the upper end profiles are lower than the plane turbulent wall profile due to the interaction between the forward and backward flows (Ead and Rajaratnam, 2002).

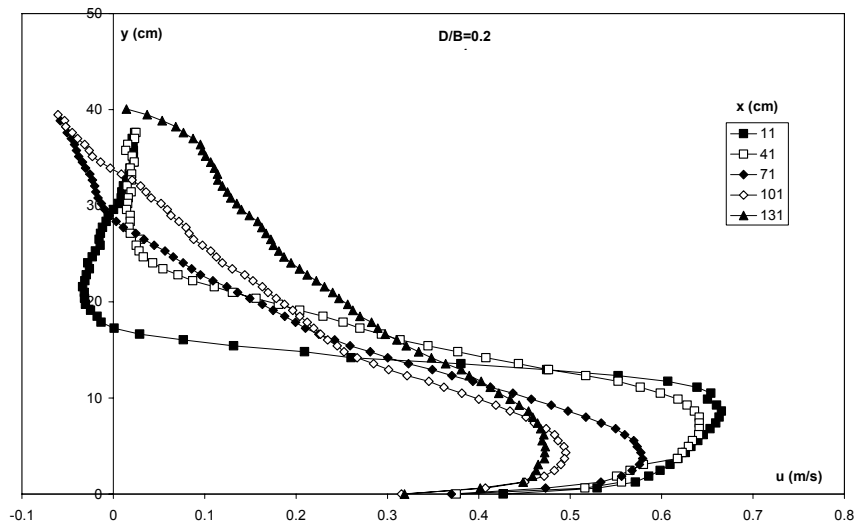
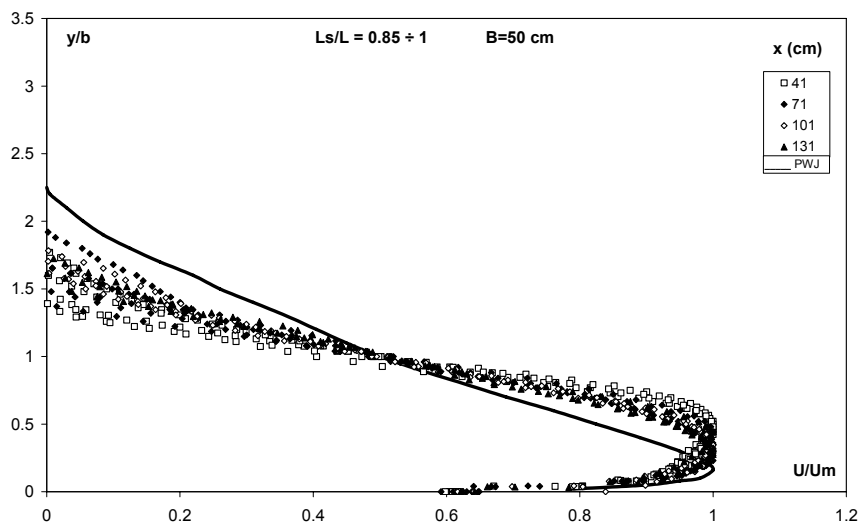
Fig. 2. Velocity profiles for $D/B=0.2$ and $L_s/L=0.85$ 

Fig. 3 Similarity profiles for the forward flow. PWJ plane wall jet profile (Rajaratnam, 1976)

Figure 4 shows typical velocity profiles in the developed flow region, for all the measurements in section 5 (s5 in Fig. 1) and for different stilling pond widths. In Figure 4, for each stilling pond width, the velocity profile corresponds to the average profile valued in the whole range of F_o . Figure shows the negligible effect of the experimental stilling pond widths on the velocity distributions.

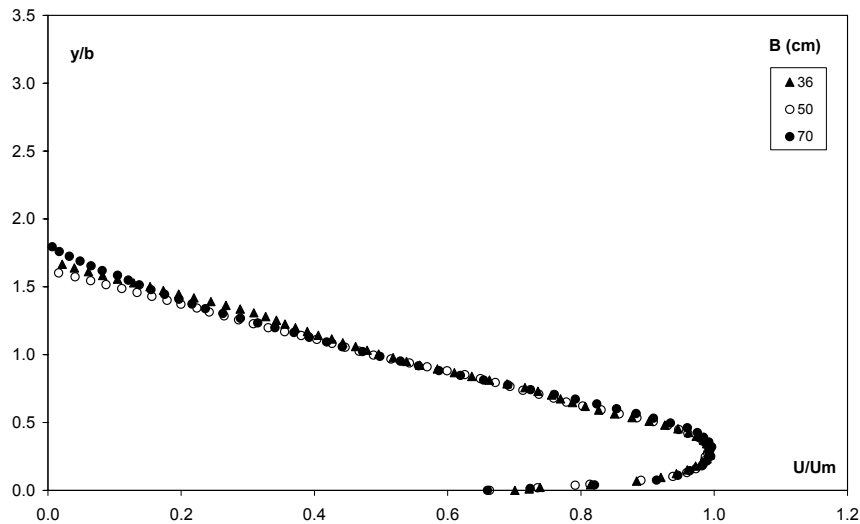
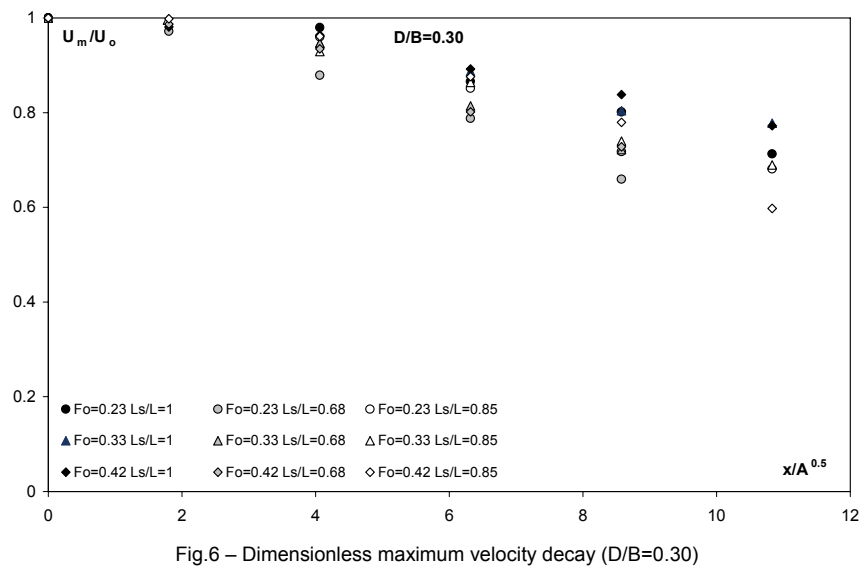
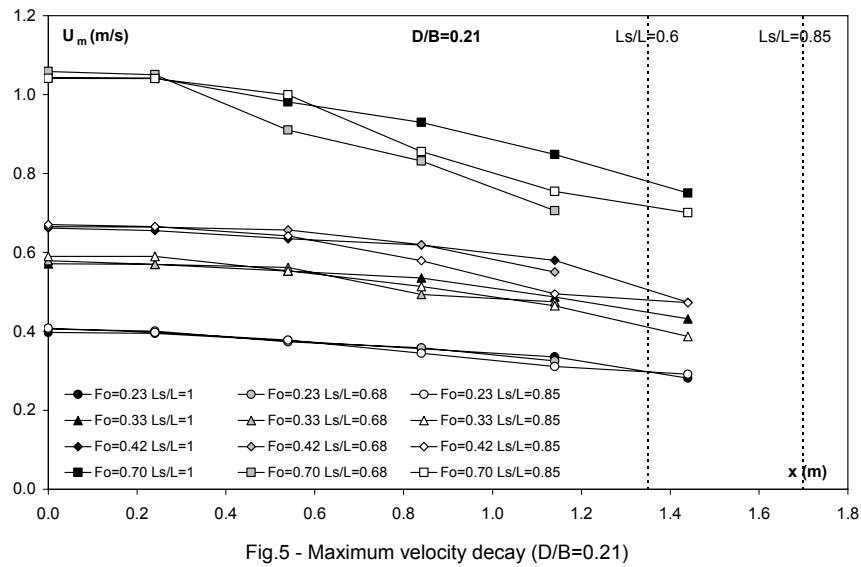


Fig. 4. Velocity distribution in the developed flow

Having found that the velocity profiles in the forward flow are quite similar, it is necessary to study the variation of the velocity scale U_m and the length scale b with the distance x . Figure 5 shows the decay of the maximum velocity with the longitudinal distance from the inlet. The maximum velocity in the central plane U_m remains almost equal to the exit velocity U_o at the pipe inlet up to the end of the potential core beyond which it decreases with x . For a water depth ratio $h/D=3$ (h is the water depth in the chamber, constant for the whole experiments), the potential core length, for a round wall jet with $Fo > 1$, is in the range 3.5–4 times $A^{0.5}$ (Rajaratman and Humphries, 1983); that is between 0.4 and 0.5 m from the pipe inlet. Fig. 5 shows the decay of the maximum velocity with the longitudinal distance from the pipe inlet for a with ratio $D/B=0.21$ (Experiment E₃).

The maximum velocity at the pipe inlet was varied from 0.4 to 1.05 m/s and U_m was measured in a number of six sections or less, depending on scumboard longitudinal position L_s . The experimental potential core length is greater than 24 cm and less than 54 cm that is in the range of Rajaratman and Humphries tests (1983).

Fig. 6 shows the decay of the maximum velocity U_m , at any section, in terms of the maximum velocity of the jet at the inlet pipe, U_o , with the normalized distance from the inlet $x/A^{0.5}$ for a with ratio $D/B=0.30$ (Experiment E2). $A^{0.5}$ is the characteristic length scale for the jet (Fischer et al. 1979) where A is the cross-sectional area of the pipe inlet. The decay of the maximum velocity is almost linear with the distance and the slopes increase with the reduction of the scumboard length ratio L_s/L . The same trend was found for a with ratio (D/B) of 0.21 and 0.42 (tests E3 and E1) confirming the irrelevance, in the range of experimental test parameters, of stilling pond width on jet characteristics. A new length scale, $x/A^{0.5} \cdot L_s/L$, was used to take in account the effect of the length ratio L_s/L on maximum velocity decay (Fig. 7 for $D/B=0.42$). All experimental data are well interpreted by a linear equation (Fig. 7) with a correlation coefficient of 0.91.



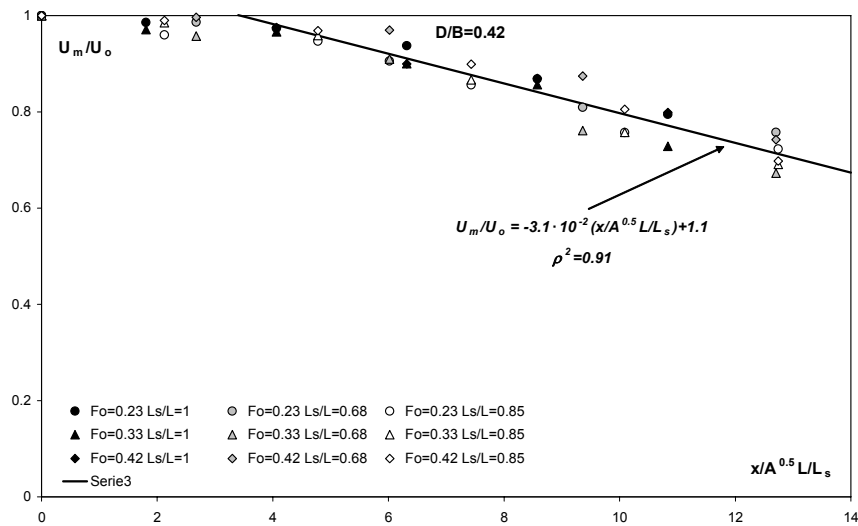


Fig.7 – Influence of length ratio L_s/L on dimensionless maximum velocity decay ($D/B=0.30$)

The growth of the length scale b of the jet (or half-width) with distance is shown in Fig. 8a e 8b respectively for $L_s/L=0.85$ and 0.68 along with the circular wall jets in stagnant flow law (Rajaratnam and Pani, 1974; Rajaratnam, 1976). The growth rate law is valid for all experimental data except for the sections near the scumboard.

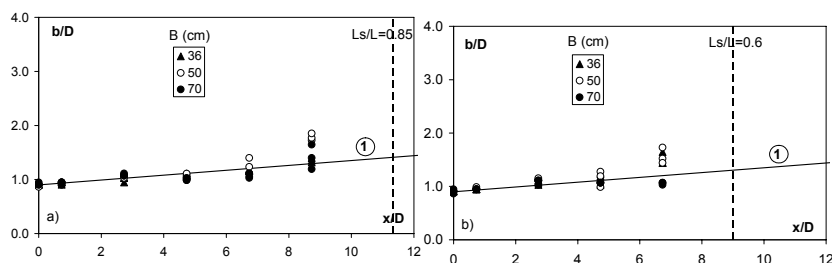


Figure 8 Variation of jet half-width with distance. 1) Circular wall jets in stagnant flow (Rajaratnam and Pani, 1974)

3 CONCLUSION

The experimental tests presented in this paper allowed to predict the hydrodynamic behaviour of the stilling pond as a particular turbulent wall jet phenomenon, due to the approach pipe in the chamber, when the ambient fluid has a limited extent. The experimental results showed that the axial velocity profiles at different sections in the wall jet were almost similar with some difference from the classical plane wall jet profile. In the experimental range parameters, the stilling pond width was irrelevant on jet characteristics. The decay of the maximum velocity U_m , at any section, in terms of

the velocity U_0 at the inlet, with the longitudinal distance x , was described by a function of $x/A^{0.5}$ and the scumboard length ratio L_s/L .

The growth rate of the length scale b of circular wall jets in stagnant flow was found to be valid except for the sections near the scumboard.

Further tests to analyze the effect of the confined ambient fluid on the wall jet volume and momentum flux are actually in progress.

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